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Production of Exotic Beams at the LBL 88-Inch Cyclotron by the ISOL Method

EB-88 Collaboration

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Production of Exotic Beams at the LBL 88-Inch Cyclotron by the ISOL Method

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Contrib. to Workshop on Science of Intense Radioactive Beams, April 10-12, 1990, Los Alamos.

Production of Exotic Beams at the LBL 88-Inch Cyclotron by the ISOL Method†

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Abstract

The Users of the LBL 88-Inch Cyclotron are preparing a proposal to produce exotic, i.e., radioactive beams. The facility will consist of a high-current 30 MeV cyclotron to generate the radioactive nuclei, an ECR source that can be coupled to different production targets, and the 88-Inch Cyclotron to accelerate the radioactive ions. Thus, the basic concept is that of the double cyclotron system pioneered at Louvain-la-Neuve, although the initial emphasis will be on producing a variety of light proton-rich beams at energies up to 10 MeV/A. At this workshop we wish to outline what is being planned, to invite comments and suggestions, and, especially, to encourage participation. We believe that this facility will be an important step toward establishing the scientific and technical basis for a National High Intensity Facility. This can be achieved through active participation by members of the radioactive beam (RB) community in (i) experiments with high quality radioactive beams of moderate intensity and, (ii) R&D on high beam-power targets and highly efficient ion sources.

1. Introduction

There are several ways to make radioactive beams and, as is the case with stable beams, no single method satisfies all needs. The ISOL approach is capable of producing beams of nuclei with half-lives longer that about 0.1 sec, with moderate to high intensity (10^6-10^{11}/sec), high energy resolution, and low emittance. The energy depends on the second accelerating system but is typically ≤10 MeV/A. Thus, this approach makes possible a wide range of experiments in nuclear structure, nuclear reactions, and nuclear astrophysics. A high intensity ISOL facility in the United States, while receiving very favorable mention in the NSAC Long Range Plan, still lies well in the future because of its cost and the financial commitments already made to CEBAF and RHIC. Along with developing the scientific case for a major future facility (whether ISOL or something else) at this workshop, it is essential to begin a stepwise approach that includes both experimental nuclear physics and R&D on the critical components of RB production. This will help develop and strengthen the community of scientists that must exist in order to justify a major RB facility. For these reasons we believe that a smaller scale and shorter term ISOL project should go forward in the U.S. The recent progress at Louvain-la-Neuve [1] demonstrates that the double cyclotron concept works and has excellent potential for further development. In the following we show how this could be accomplished at the 88-Inch Cyclotron.

2. Concept

A schematic reminder of the main components in the system and the order-of-magnitude intensities in the different stages is shown in Fig. 1. There are at least two providers[2,3] of compact 30 MeV H^- and 15 MeV D^- cyclotrons, with prices starting at $3M. The typical thick-target yields for (p,n) reactions leading to the lighter isotopes of carbon, nitrogen and oxygen vary from 10^{-4} to 10^{-3} per proton. Depending on the fraction of these atoms that can be extracted from the target and ionized in the ECR source to the desired charge state (2^+ - 4^+), the intensities of ions injected into the 88-Inch Cyclotron should vary from 10^7 to 10^{10}/sec. The cyclotron has an acceleration efficiency of typically 10%, which leaves 10^6 to 10^9 ions/sec for experiments.

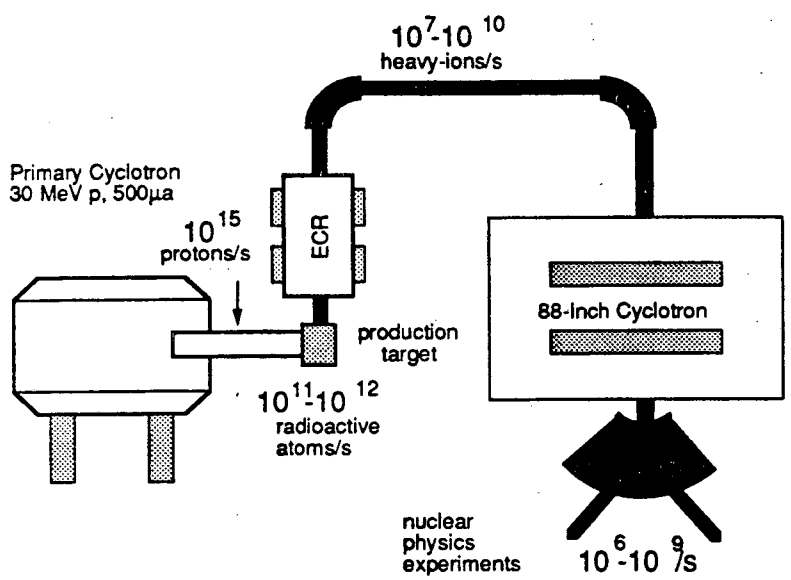


Figure 1.

3. Beams

There are about twenty proton rich isotopes from ^{7}Be through ^{30}P having half-lives of a second or longer that might eventually be obtainable as beams. But the approximately ten species with Z≤11 seem to be the ones to develop first, and of these, experimenters have so far expressed the most interest in ^{10}C(19s), ^{11}C(20m), ^{13}N(10m), ^{14}O(1.2m), and ^{15}O(2m). Neutron-rich beams could be developed in time as manpower and interest permit, and could be obtained in two ways: via the (n,p) reaction using neutrons produced by deuterium bombardment of ^{9}Be, or via the (p,3He) and (d,3He) reactions. These beams are expected to have intensities lower by one or perhaps two orders of magnitude.

The maximum beam energy of the 88-Inch Cyclotron (in MeV/A) is 140 $(q/A)^2$, the energy resolution is 0.3%, and the emittance is 20 π mm mrad.

4. Science

There is a wide range of possible experiments, even when considering only the proton-rich species. A number of scientists interested in EB-88 have suggested specific experiments in:

•Nuclear Astrophysics ($^{14}O+\alpha \rightarrow {}^{17}F+p$)	(E. Norman)
•Reactions and Structure of Mirror Nuclei ($^{11}C + {}^{11}B$ and $^{13}N + {}^{13}C$)	(J. Cerny)
•Nuclear Physics at the Proton Drip Line (e.g., studies of $^{11,12}N$, $^{15,16}F$, etc.)	(H. Weller; F. Ajzenberg-Selove))
•Isospin Mixing in the GDR ($^{13}N + {}^{13}C$, $^{14}N + {}^{12}C$)	(K. Snover)
•Spectroscopy of Proton-Rich 1f-2p Nuclei (e.g., $^{14}O + {}^{40}Ca \rightarrow$)	(P. Haustein; F. Stephens; J. Becker)
•Subbarrier Fusion and Transfer ($^{15,16}O + {}^{143,142}Nd$)	(R. Stokstad)

Some of these experiments are quite new, others are not, and collectively they represent only a beginning. We hope that through this workshop more people will become involved in the generation of ideas for experiments with EB-88.

With its present high efficiency ECR sources the 88-Inch Cyclotron has accelerated stable beams that, because of their isotopic rarity, can also be considered "exotic". Examples are $^{29,30}Si$, ^{34}S, ^{36}Ar, ^{48}Ca, and ^{136}Xe. The combination of radioactive and exotic stable beams made possible by EB-88 would provide unique opportunities for experiments with existing instrumentation (the Ge-detector array HERA, the large NaI spectrometer, particle detector arrays, etc.).

5. Physical Layout

A primary consideration in the design has been flexible operation for both experiments and R&D, and the ability to handle highly activated targets. This necessitates having several high-level caves instead of just one, and adequate shielding to prevent activation of adjacent caves during a production run. Fig. 2 shows the primary cyclotron enclosed in a vault having walls of boron-doped concrete, about four feet thick [4]. There are three beam lines, each equipped with a quadrupole triplet and ending in one of three caves. The cave doors move vertically on hydraulic lifts. The experimental area adjacent to the caves has controlled access through double doors. Provision for storage and remote handling of targets is included, although the details of this have yet to be designed. Since negative ion cyclotrons offer the possibility of extraction on either side of the

cyclotron, ports for testing of targets or production of isotopes at lower intensities are indicated, and could be developed as needed.

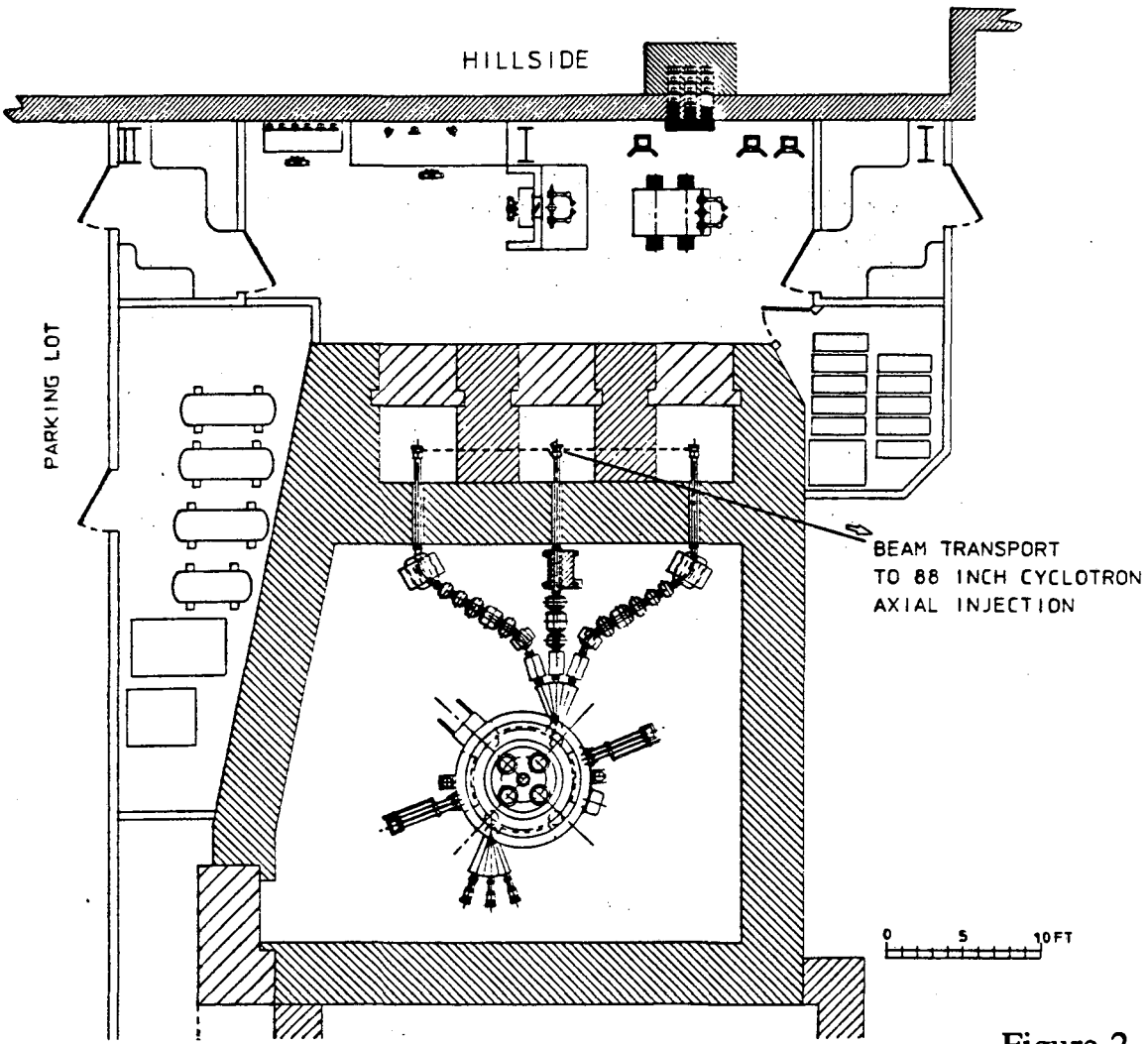
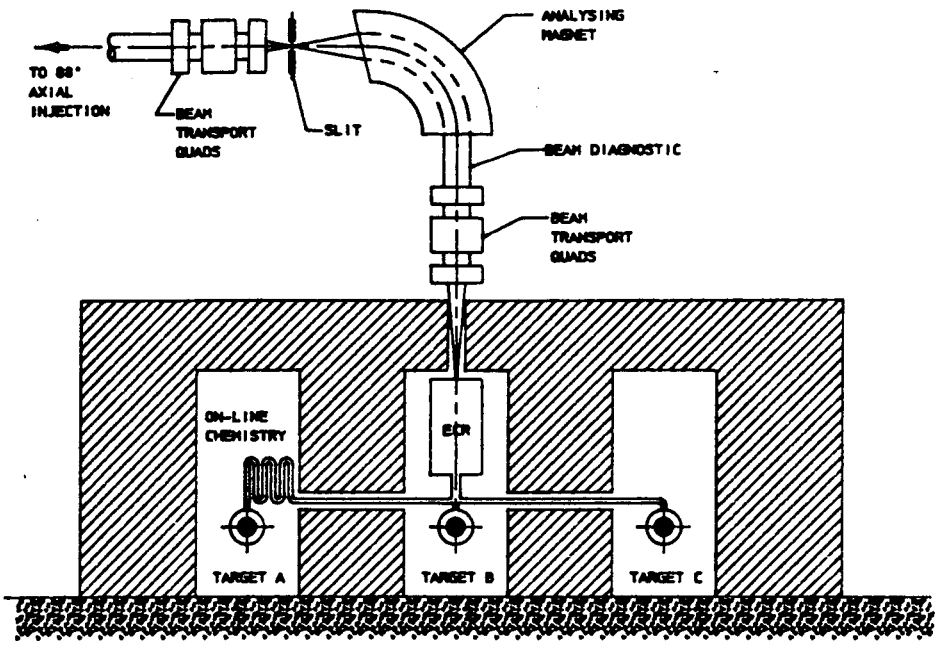


Figure 2.

6. Targets and Ion Source

The ECR ion source is mounted vertically and located in the middle cave, as shown in the elevation drawing of Fig. 3. Thus, the ECR source can be fed by a gas transport system from a target in the adjacent cave on either side, or can be operated in an integral mode with the target in the center cave. Some shielding between this target and the ECR source would be possible at the expense of a slightly longer distance between target and source. Provision has been made for local servicing or removal of the ECR source through movable roof blocks. Finally, Fig. 4 shows a schematic design of a target that is essentially integral with the ECR source, the connection being made by a heated transfer tube. The ECR source has a heated liner for high efficiency and short hold-up times.



EB-88 TARGET CAVES
ELEVATION VIEW

Figure 3.

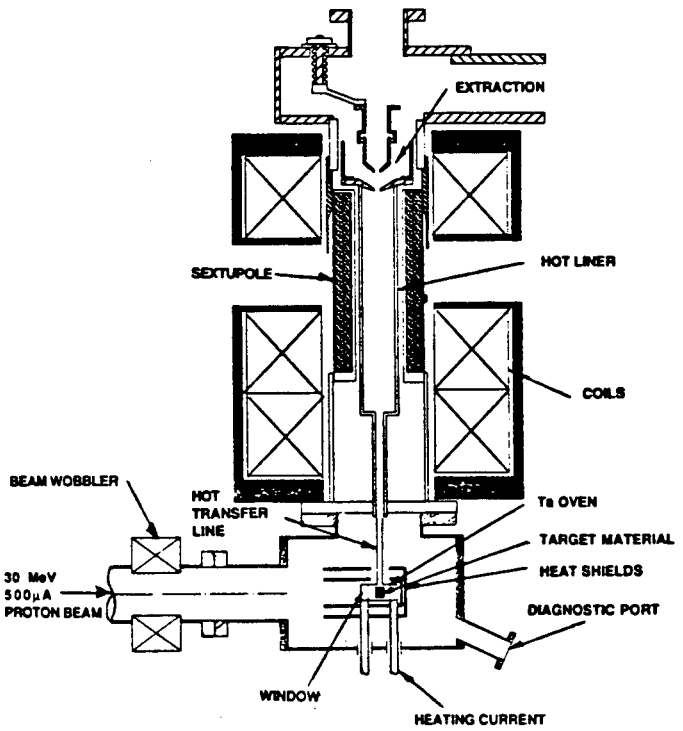


Figure 4.

7. Research and Development

There are three levels of R&D in this project. The first level uses existing equipment and is therefore near-term, while the second and third require EB-88.

1.(a) *Studies of target characteristics at moderate beam-power levels, up to 1.5 kW, using the proton beams from the 88-Inch Cyclotron.* (Initial investigations of a boron nitride target have been made with beams of a few microamperes [5]). This R&D can begin in earnest in the very near future with the design of a prototype target for studying different materials, temperatures, production reactions, etc. Presently, this activity is manpower limited: wider participation is most welcome.

(b) *Investigations of ECR source efficiency and hold-up times using the existing LBL-ECR source.* The Advanced ECR source will be connected to the 88-Inch Cyclotron this summer, freeing the present source for this work. Manpower here is also in short supply.

2. *R&D at higher power levels and with the dedicated ECR source once the facility is constructed.* This would support mainly the development of different beams and higher intensities at this facility, though it would obviously have wider relevance. This type of R&D would go on continuously.

3. *R&D directed specifically toward the problems of a future high intensity facility.*

There are many ways in which the use of this facility for experiments and for R&D is relevant for a future high-intensity facility, especially of the ISOL type. For brevity these are summarized as follows:

Relevance of EB-88 to a future high intensity RB facility

- Primary Beam:
  handling, diagnostics, safety, total power = 15(50)kW,
  longitudinal power density = 20(1) kW/cm. (The values in parenthesis are for a high intensity facility.)
- Targets:
  element-specific target matrices,
  fast diffusion and surface desorption,
  high yield, low vapor pressure, temperature control,
  beam power distribution.
- Beam Purity:
  element selective transport from target to ion source,
  fast on-line chem./phys. separation techniques.

- Ion Sources:
  high efficiency ECR for intermediate 2^+ - 4^+ charge states (charge state influences design and cost of second accelerator!), radiation hardened materials/components.
- Experiments:
  working with low RB intensities, beam impurities, background from RB itself, detector efficiencies.
- Safety Issues:
  primary beam, target/ion-source handling, robotics, post-accelerator contamination, shielding, containment.
- Education:
  training of the next generation of students and postdocs in the science and technology of radioactive beams.

In brief, R&D questions can be addressed today, and R&D flourishes when science can be done simultaneously.

8. Cost and Schedule

The cost is estimated at $7.5 M (FY90), which includes about $3.2 M for the high current cyclotron. With FY93 capital funding, operation for research would begin in FY '95.

Questions, comments, and inquiries about participation are most welcome, and can be addressed to any of the following people at the Workshop: D. Clark, K. Gregorich, P. Haustein, D. Hoffman, D. Moltz, M. Nitschke, F. Stephens, and R. Stokstad

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2. Ion Beam Applications, Louvain-la-Neuve, Belgium
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* EB-88 stands for "Exotic Beams at the 88-Inch Cyclotron", and the Collaboration, not a formal organization, consists of people from several institutions who devote, or would like to devote, time to this collective effort.

R. G. Stokstad,
for the EB-88 Collaboration

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